DEEP TILLAGE EFFECTS ON POTATO YIELD AND QUALITY

by
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INTRODUCTION

About 3.7 million acres are surface irrigated in Washington, Oregon, and Idaho. In 1988 about 506,000 acres were in potato production. In recent years there has been a substantial shift away from furrow to sprinkler irrigation of Russet Burbank potatoes. The two main factors causing this shift have been soil erosion and production quality.

Erosion is a severe threat to sustainability of Pacific Northwest agriculture. The region's irrigated soils are derived from ash and loess, low in organic matter and clay, and have weak structure with few durable aggregates. From 2.2 to 22.3 ton acre^{-1} yr^{-1} can be lost from typical fields, and three times that from near the furrow inlets. As much as 22.6 ton acre^{-1} loss from one 24 hr irrigation has been documented. In some fields this has caused the complete loss of surface horizons in only decades. Since many arid soils have calcium carbonate-rich subsurface layers, their exposure, or mixing with remaining surface soil, causes plant nutrient deficiencies and soil physical problems. These "white soils" usually reduce crop productivity and increase the inputs required to sustain yields. Erosion can be reduced by increasing infiltration, which raises irrigation efficiency and reduces runoff. Lowering soil bulk density and increasing porosity through deep tillage provides for such an increase in infiltration.

Inadequate wetting of the hill in furrow irrigated fields of Russet Burbank potatoes has been implicated as a problem affecting quality. Inadequate water during hot weather, or tuber exposure to a combination of dry soil and high soil temperature in the beds before complete canopy coverage can stress and damage the developing tubers. Compaction can worsen these problems by preventing rooting into wetter parts of the soil, and by forcing tuber set higher in the bed where temperatures are higher and moisture is less. Compaction may not prevent rooting or tuber set, but expanding tubers may become physically constrained.

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Compaction management can only be accomplished in the long term by reducing traffic, confining traffic to limited traffic lanes, or by using rotations and cultural practices that promote soil organic matter conservation and soil aggregation. In the short run, some form of deep tillage is required. Zone-subsoiling (sometimes called precision subsoiling or in-row subsoiling) is more cost effective than overall loosening, and maintains firm traffic lanes for later field entry. Deep tillage research with irrigated potatoes has demonstrated the potential for improved yield and quality, particularly for the Russet Burbank variety. Most studies were conducted under sprinkler irrigation because confining water delivery down the intended furrow can be a problem if deep tillage is extensive (broadcast). It was not clear if this would occur if subsoil loosening were confined to the zones directly under the bed, leaving the furrow area undisturbed.

These studies determined the influence of zone-subsoiling on infiltration, runoff, furrow-erosion and potato yield and quality. The results are summarized for a number of studies utilizing a variety of irrigation systems.

APPROACH

Deep plowing to alleviate compaction is not widely practiced because soil inversion on many of these soils can invoke serious nutritional consequences caused by the high lime content of deep soil layers. The Tye Paratill[1] is a new implement which loosens the subsoil to a significant depth without inversion or significant lateral or vertical soil displacement. Various configurations of the implement allow either complete subsoil loosening, or zone loosening, where compacted lanes are required for traffic or furrow irrigation.

In 1989 a number of studies were initiated to evaluate the effect of post-plant zone-subsoiling with the Paratill on the yield and quality of irrigated potatoes in the Snake River Plain. In all of these studies essentially standard production practices, chemicals, and fertilizers were used. Zone-subsoiling with the paratill was usually performed within a week to ten days after planting and was the last machinery pass through the field in spring with no further traffic prior to harvest. The studies encompassed a variety of irrigation techniques and some of the results are interpreted in relation to irrigation practices. Because a number of diverse studies are summarized in this report certain aspects of the data were treated differently from study to study. We have attempted, as much as possible to make fair comparisons from one study to the next. Nonetheless these results are only brief summaries, and are largely preliminary interpretations. The study sites are described briefly in table 1.

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1 Mention of trademarks, proprietary products, of vendors does not constitute a guarantee or warranty of the product by the USDA or the Idaho Agricultural Experiment Station, and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

Table 1. Summary of Idaho experimental sites:

LOCATION	YEARS	EXPERIMENT TYPE	IRRIGATION TYPE	VARIETY
1. Kimberly	89 & 90	Farm-Cooperator	Solid set spr.	Norkotah
2. Kimberly	89 & 90	Experiment Stn.	Furrow	RussetBurbank
3. Kimberly	89 & 90	Experiment Stn.	Simulated Pivot	Russet Burbank
4. Aberdeen	89	Experiment Stn.	Simulated Pivot	Russet Burbank
5. Burley	90	Farm-Cooperator	Center Pivot	Russet Burbank
6. Parma	90	Experiment Stn.	Solid set spr.	Russet Burbank

In each study zone-subsoiled treatments were compared to identically treated plots which had not been subsoiled. Studies #3, 4, & 5 included a comparison with reservoir-tillage (dammer-diker) treatments. Studies 2, 3, 4 and 5 all contained subtreatments which were pooled for this paper in order to focus discussion primarily on the effects of zone-subsoiling. Studies 3 and 4 used experimental overhead linear-move systems, which are essentially small segments of center pivot irrigation systems. Plot sizes, statistical designs, and sampling techniques varied from location to location.

SOIL AND WATER OBSERVATIONS

The paratill left good bed configuration at all sites. Furrow shapes were readily maintained using shovel openers or weighted sleds attached to the paratill between beds. Excavation of tilled beds revealed no substantial seed piece dislocation or damage to budding seed pieces. In 1990 zone-subsoiling was delayed 23 days after planting at site #1, and seed had sprouts 1-2 inches long, but excavation throughout the field revealed no damage to sprouts, and emergence was not impaired. Vines in zone-subsoiled plots emerged 3-4 days earlier than in non-subsoiled plots in most studies. Measurement of early emergence (stand counts and plant weights) in 1990 at site #2 indicated both earlier and more uniform emergence in zone-subsoiled plots.

In the 1989 furrow irrigated plots (site #2) some cracking of the beds resulted from alternating the first two thorough irrigations among wheel track and non-wheel track sides of the beds. This prompted concern that cracks would admit sufficient light into the beds to cause greening of tubers. Careful inspection of tubers at harvest, however revealed no adverse effect of bed cracking. When furrow irrigating the non-wheel track sides of beds, furrow water sometimes "piped" into the discontinuity caused by the paratill shanks (which are offset to the sides of the beds). This would cause water to run under the beds for 10 to 15 minutes in some cases before flow resumed along the furrow. Although this was an inconvenience, it did not result in adverse affects on yield or quality. Piping was a greater problem in the non-wheel furrows of zone subsoiled treatments. Presumably the more diffuse fraction area and the compaction from wheel passage of the deep tillage operation promoted better furrow shaping and water conveyance. Piping was most pronounced in the first few irrigations of each season, after which it was not as serious. In 1990 plots were briefly surge irrigated on both sides of the bed during the first irrigation to condition furrows.

This reduced but did not completely eliminate piping and bed cracking compared to the first year's experience. The piping problem would discourage the use of zone subsoiling by some furrow irrigators. With attention to initial furrow shaping and by tending problem furrows in the first few irrigations, however, the piping problem need not preclude use of the zone-subsoiling concept under furrow irrigation.

High bulk density is a measure of soil compaction. The most common field preparation for potatoes in Idaho is fall plowing without spring zone-subsoiling. Fall disking without spring subsoiling represents the most compaction-prone tillage practice likely to be encountered in normal commercial production, and the fall plowed plus spring zone-subsoiled treatment represents the greatest compaction disruption likely feasible for commercial production. Measurement of bulk density in study #1 and 2, using a gamma ray density probe, showed that bulk density was reduced by zone-subsoiling and remained lower than fall-plowed or fall-disked plots throughout the season (Table 2.). These measurements were made after initial soil consolidation caused by early-season irrigation. This indicates that the looser beds persist long enough to influence tuber formation and the ease of digging at harvest. Bulk density differences with or without zone-subsoiling were most pronounced at the 12 inch depth. The looser beds of the zone-subsoiled treatments also contributed to a slight warming (about 1°F) of the beds in the first month after subsoiling (data not shown). The warmer and looser beds of zone-subsoiled treatments were likely responsible for observed earlier and more vigorous emergence.

Table 2. Bulk densities determined in the center of beds of three tillage treatments, using gamma ray backscattering.

	Bulk Density g cm^{-3}								
	Disk Only			Plow Only			Plow+ Zone-Subsoil		
	---1989---		1990	---1989---		1990	---1989---		1990
SITE #2									
Depth inches	6/28	8/16	8/02	6/28	8/16	8/02	6/28	8/16	8/02
6	1.27a	1.26a	1.15a	1.25a	1.25a	1.11a	1.15b	1.23a	1.05a
12	1.35a	1.33ab	1.41a	1.36a	1.38a	1.36a	1.24b	1.24b	1.16b
18	1.35a	1.36a	1.52a	1.38a	1.44a	1.45ab	1.37a	1.37a	1.37b
SITE #1									
	Disk Only						Disk+ Zone-Subsoil		
6			1.09a						1.06a
12			1.44a						1.07b
18			1.58a						1.31b

Values in the same row for the same date with the same letter do not differ at the 5% level of probability.

Figure 1

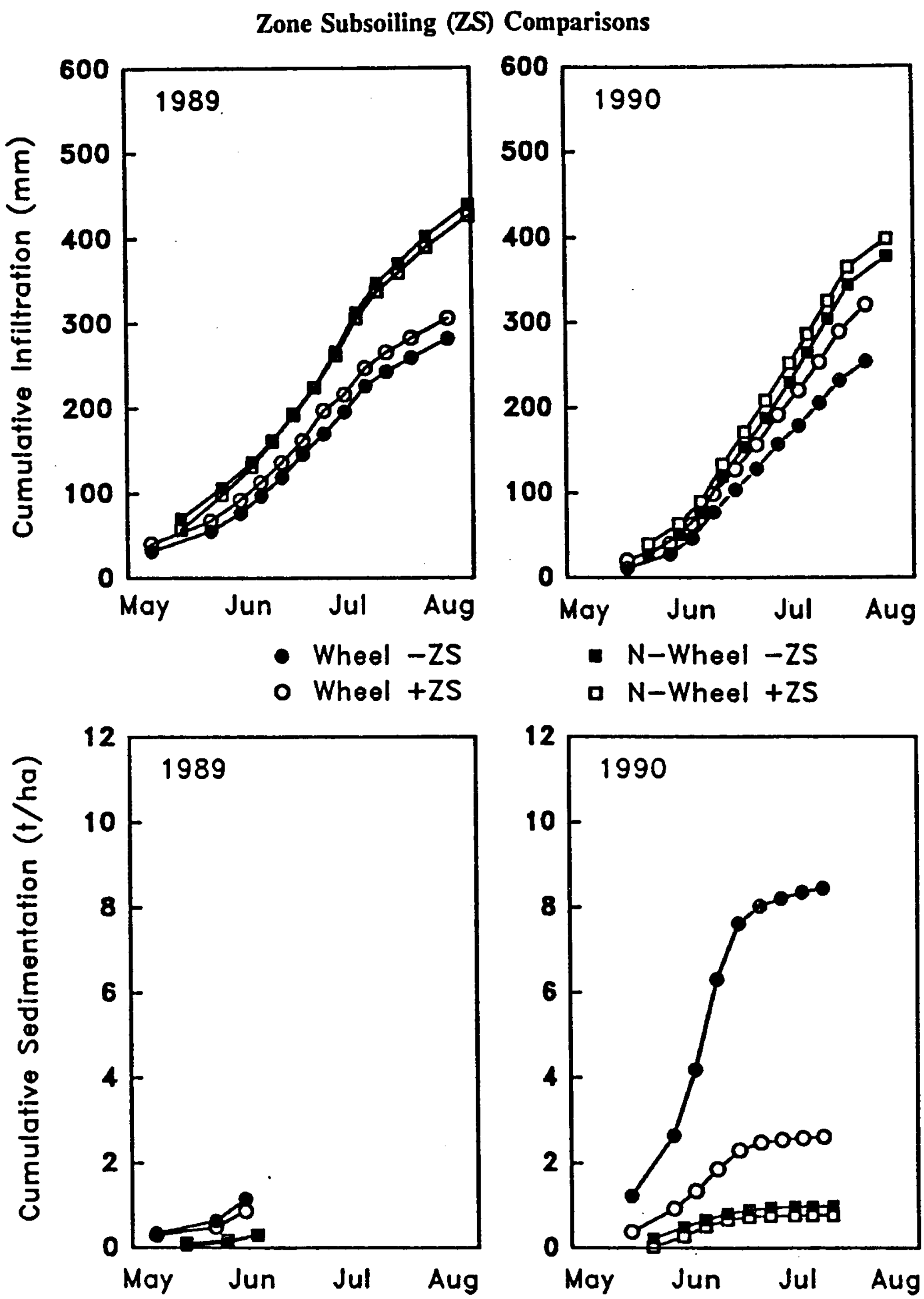
Zone Subsoiling (ZS) Comparisons
Cumulative Infiltration (mm)
1989
1990
600
500
400
300
200
100
0
May
Jun
Jul
Aug
Wheel −ZS
Wheel +ZS
N−Wheel −ZS
N−Wheel +ZS
Cumulative Sedimentation (t/ha)
12
10
8
6
4
2

Table 3. Season summary of water application, runoff, and net infiltration for Site #2.

	Wheel Furrows				Non-Wheel Furrows*				Net Infiltration	
	Flow on	Run off	Net Infiltration		Flow on	Run off	Net Infiltration		All Total	Furrows Mean
TREATMENT	mm	mm	mm	%	mm	mm	mm	%	mm	%
	1989									
Mean -ZS	591	310	281	47.6	602	162	439	73.0	721	60.4
Mean +ZS	591	286	306	51.7	609	183	426	70.0	732	61.0
	1990									
Mean -ZS	446	192	254	56.8	446	69	377	84.6	631	70.7
Mean +ZS	446	125	321	71.9	446	48	398	89.2	718	80.5

*Use or no use of zone-subsoiling is indicated by +ZS or -ZS respectively.

Table 4. Cumulative sediment loss, and cumulative infiltration restricted to dates of sediment monitoring, and their interrelationship for Site #2.

	Wheel Furrows			Non-Wheel Furrows			All Furrows	
	Sediment Loss	Net Infil.	Sed.: Infil.	Sediment Loss	Net Infil.	Sed.: Infil.	Sediment Loss	Sed.: Infil.
TREATMENT	kg ha^{-1}	mm	kg mm^{-1}	kg ha^{-1}	mm	kg mm^{-1}	kg ha^{-1}	kg mm^{-1}
	1989							
Mean -ZS	1154	77	15.00	315	136	2.31	1469	6.90
Mean +ZS	871	92	9.45	297	131	2.27	1168	5.24
	1990							
Mean -ZS	8450	205	41.16	976	304	3.21	9428	18.52
Mean +ZS	2604	253	10.29	771	325	2.37	3388	5.84

*Use or no use of zone-subsoiling is indicated by +ZS or -ZS respectively.

Cumulative infiltration patterns for zone-subsoiled and non-subsoiled treatments at site #2 appear in Figure 1, and infiltration results appear in Table 3. Fall tillage treatments of disking, chiseling, or plowing affected these results, but data are not shown because of space limitations. For all the data, net infiltration of wheel track furrows was less than net infiltration of non-wheel furrows. In 1989 wheel track furrow infiltration from zone-subsoiled treatments was equal to or higher than from non-subsoiled treatments. In all cases except with fall plowing in 1989 zone-subsoiling infiltration exceeded or was equal to non-subsoiled treatments. Reduction of infiltration occurred in the "non-wheel track" furrow of fall-plowed treatments because of planting equipment traffic patterns. This affected the net infiltration of zone-subsoiled plots across the three fall-tillage treatments.

Care was taken in the second year of this study to assure that wheel patterns for the planting and subsoiling operations were in the same furrows. Greater soil moisture in the spring of 1990 also accentuated the relative differences between wheel track and non-wheel track infiltration. The 1990 infiltration results are probably more representative of what can typically be expected with or without zone-subsoiling. In 1990 there was a consistenly higher net infiltration in non-wheel furrows regardless of fall tillage. Similarly, net infiltration was greater for zone-subsoiled plots regardless of fall tillage and irrespective of wheel or non-wheel furrow.

The amount of erosion from furrow irrigation at site #2 in 1989 and 1990 are summarized in Figure 1 and Table 4. The magnitude of sediment loss increased three to six fold from 1989 to 1990. Water applied and infiltrated were similar both years, but in 1990 field slope and application rate were greater, and in 1990 potatoes followed beans, compared to wheat in 1989. Sediment sampling was terminated for the 1989 season in mid June when sediment concentrations decreased below 0.5 g l^{-1} in nearly all plots. Sediment losses in 1989 from non-wheel furrows were less than from wheel furrows but were similar regardless of fall tillage.

In 1990 the sediment losses were clearly driven by runoff differences among treatments. Where infiltration was improved, furrow sediment loss was reduced. Wheel track furrows lost more sediment than non-wheel furrows. Non-wheel furrow sediment loss was not substantially affected by tillage practice, producing low amounts of sediment in all cases. In wheel track furrows, sediment loss was three to four fold greater without zone-subsoiling. Differences in sediment loss rate became nearly non-existent by July as the canopy closed and vines intruded into furrows. Although differences in infiltration largely dictated the direction of change in erosion from the various tillage treatments, it is apparently not the only factor. Although infiltration varied by as much as twenty percentage points among tillage treatments, the ratio of sediment lost to water infiltrated (data not shown) varied by several fold among treatments. The sediment to infiltration ratio was particularly reduced by zone-subsoiling. If infiltration alone had caused the differences these ratios would have been nearly constant. The ranking of sediment loss was not perfectly consistent between years. Generallly, however, zone-subsoiling substantially reduced sediment loss, especially in the mcre erosive wheel track furrows.

YIELD AND QUALITY OBSERVATIONS

Yield and quality data for site #1 (Norkotah) are presented in Table 5. These data indicate a yield and quality advantage in 1989 for zone-subsoiling with the Paratill. In 1989 total yield increased by 35 cwt/a (10.1%) but was not statistically significant at the 10% probability level. The percent of yield of #1 potatoes greater than 10 oz increased from 16% to 25% with zone-subsoiling. Although the percent of #1 potatoes of 4 to 10 oz size decreased from 53% to 46% with zone-subsoiling, this merely reflected the shift in size distribution to the >10 oz range, with the total percent of #1 potatoes approximately equal for either tillage treatment. In 1990 Norkotah potatoes were affected statewide by late frosts and a variety of diseases. As the drop in 1990 yields in Table 3 suggest, this site was among the fields affected. Zone-subsoiling had no effect on yield or grade in 1990. Although a decrease in specific gravity often accompanies an increase in size it was not affected statistically by zone-subsoiling either year.

Table 5. Yield and quality of solid-set sprinkler irrigated Norkotah potatoes with or without zone-subsoiling, in Kimberly, Id., 1989 and 1990.

Tillage Trtmt.	Year	Yield cwt/a	% #1 >10 oz	% #1 4-10 oz	Specific[1] Gravity
Zone-subsoil	1989	382	25	46	1.0738
	1990	247	11	62	1.0733
Conventional	1989	347	16	53	1.0756
	1990	259	9	64	1.0726
Probability	1989	NS	3.4%	NS	NS
	1990	NS	5.9%	NS	NS

[1]Determined on a subsample of #1's and #2's combined.

Yield and quality results favored zone-subsoiling in both 1989 and 1990 for the furrow irrigated Russet Burbank study conducted at site #2 (Table 6). In 1989 total tuber yield, percent of #1 and #2 tubers greater than 10 oz combined, and tuber specific gravity did not differ statistically at the 5% level of probability, although all three showed favorable trends with zone-subsoiling. Zone-subsoiling increased the yield of #1 tubers by 33 cwt acre^{-1}, which was significant at the 3.5% level of probability. In both 1989 and 1990 zone-subsoiled plots, the more vigorous early season growth probably contributed to the observed improvement in grade. In 1990 early stand counts and plant weights were made. In 1990 top-growth dry weight of non-subsoiled treatments on June 5th was only 69% zone-subsoiled plots (data not shown). Individual plant size was also more uniform with zone-subsoiling. Similarly, whole plants sampled on July 18 and August 27 indicated greater top dry weight, tuber fresh weight, and tuber dry weight for zone subsoiled treatments. Yield and percent #1's were increased by 11% and 12% respectively in 1990 by zone-subsoiling, but again with no effect on percent greater than 10 oz or specific gravity.

Table 6. Yield and quality of furrow irrigated Russet Burbank potatoes, with or without zone-subsoiling, in Kimberly, Id., 1989 and 1990.

Tillage Trtmt.	Study Year	Yield cwt/a	Percent # 1's	Percent[1] > 10 oz	Specific[2] Gravity
Zone-subsoil	1989	351	63	40	1.0795
	1990	374	64	20	1.0832
Conventional	1989	324	58	39	1.0786
	1990	337	57	19	1.0832
Probability	1989	NS	3.5%	NS	NS
	1990	0.1%	5.9%	NS	NS

[1]Greater than 10 oz for #1's and #2's combined.
[2]Subsample of #1's and #2's combined.

The study at site #3 included a comparison of reservoir-tillage on otherwise conventionally tilled plots. The irrigation of this study provided application of water at a high rate. In both 1989 and 1990 there was little or no runoff (data not shown) from plots that were reservoir-tilled or zone-subsoiled and reservoir-tilled. The greatest amount of runoff occurred from conventionally tilled plots and an intermediate amount of runoff occurred from plots that were zone-subsoiled with the paratill but not also reservoir-tilled (dammer-diked). Yield and quality results (Table 7) were, therefore, strongly related to the amounts of water infiltrated, even though water was applied to prevent predicted depletion below 65% available water holding capacity (because the "checkbook" method assumed no runoff). In 1989 yield and quality of the conventional and zone-subsoiled plots were nearly identical, while total yield and percent #1's tended to improve with reservoir-tillage. It is difficult to completely interpret the tillage response in this case, since if the application rate were reduced and application frequency or duration were increased to provide the total water requirement of the crop, the yield and quality relationships may have proved different. In 1990 yield and quality are again variable but tend to be slightly improved over conventional tillage by zone-subsoiling. Again overall specific gravities were not significantly affected by tillage treatments. The performance of zone-subsoiling coupled with reservoir-tillage was superior to either one alone. On the whole, these results indicate that if irrigation is not managed to prevent runoff, and provide adequate intake, then subsoil loosening will not improve yield or quality. Zone-subsoiling and reservoir-tillage combined provide a highly effective means of increasing intake efficiency that appear to improve both yield and quality.

Table 7. Yield and quality of high rate (simulated center pivot) sprinkler irrigated Russet Burbank Potatoes, affected by zone-subsoiling (paratill) and reservoir-tillage (dammer-diker), Kimberly, Id., 1989 and 1990.

Tillage Trtmt.	Study Year	Yield cwt/a	Percent #1's	Percent[1] > 10 oz	Specific[2] Gravity
Zone-subsoil	1989	285	31	13	1.0764
	1990	324	60	22	1.0801
Conventional	1989	285	32	19	1.0778
	1990	320	66	12	1.0780
Reservoir-till.	1989	313	49	16	1.0772
	1990	319	71	14	1.0805
Zone-subsoil +	1989	---	--	--	------
Reservoir-till.	1990	370	68	17	1.0807
Probability	1989	NS	5.8%	4.9%	NS
	1990	NS	2.4%	NS	NS

[1]Greater than 10 oz for #1's and #2's combined.
[2]Subsample of #1's and #2's combined.

The study at site #4 was conducted under a similar irrigation system to that described for site #3 (only 1989 data were available at this writing). In this study total yield was slightly lower (5.6%) for zone-subsoiled plots (Table 8), but overall quality was higher. Zone-subsoiling produced 190 cwt/a of #1's vs 169 cwt/a of #1's for conventional tillage, and of these #1's zone-subsoiling produced 51 cwt/a > 10 oz vs 23 cwt/a produced by conventional tillage. Again specific gravity did not differ significantly.

Table 8. Yield and quality of high application rate (simulated center pivot) sprinkler irrigated Russet Burbank Potatoes, with or without zone-subsoiling at Aberdeen, Id., 1989.

Tillage Trtmt.	Yield cwt/a	% #1 >10 oz	% #1 4-10 oz	Specific[1] Gravity
Zone-subsoil	234	27	54	1.0807
Conventional	248	14	54	1.0817
Probability	NS	0.3%	NS	---

[1]Determined on 4 to 10 oz #1's.

The study at site #5 was conducted in 1990 under a large center pivot system near Burley, Id. Treatments were similar to those described for site #3. Yields and quality appear in Table 9. Again intake and runoff (data not shown) was affected by tillage and these effects followed the same relative patterns described for site #3. Grade differences among tillage treatments were not statistically significant, although when examined in the context of the data from the other studies there is the familiar pattern of a greater percent of USDA #1 potatoes with zone-subsoiling, reservoir-tillage, or the two combined. Similarly the percent of culls were higher for the conventionally tilled treatment. The effect of tillage on total yield showed a strong "trend" (Probability level of 11%) for greater yield with zone-subsoiling, reservoir-tillage or the two combined.

Table 9. Yield and quality of high application rate (center pivot) sprinkler irrigated Russet Burbank Potatoes, with or without zone-subsoiling at Burley, Id. 1990.

Tillage Trtmt.	Yield cwt/a	Percent #1's	#2's	Culls
Zone-subsoil	272	45	30	25
Conventional	216	40	24	36
Reservoir-tillage	284	50	24	26
ZS + RT	252	52	19	29
Probability	11%	NS	NS	NS

The study at site #6 was conducted in 1990 under solid set sprinklers in Parma, Id. This study consisted of a simple comparison of zone-subsoiling and conventional tillage. Yield and quality results appear in Table 10. Although some early season increase in top growth was seen at this site with zone-subsoiling, no significant yield or quality differences were detected between tillage treatments. This was somewhat of a surprise because of the distinct traffic pan at this site. These first year's results bear further investigation to determine if additional management considerations are warranted.

Table 10. Yield and quality of solid set sprinkler irrigated Russet Burbank potatoes, with or without zone-subsoiling at Parma, Id. 1990.

Tillage Trtmt.	Yield cwt/a	% #1 4-10 oz	% #1 >10 oz	Specific Gravity[1]
Conventional	420	74.5	22.7	1.081
Zone-subsoil	418	72.1	18.6	1.079
Probability	NS	NS	NS	NS

[1]Determined on 4 to 10 oz #1's

CONCLUSIONS

These data are cursory summaries from several continuing studies, performed with a wide variation of objectives and management. Each study will be analyzed in greater detail in time for more comprehensive presentation by the responsible researchers. Some of the studies remain ongoing and will be repeated for additional verification in coming seasons. Certain results seem consistent enough to bear summarization.

On the positive side:

1. Zone-subsoiling can be performed as late as one to two weeks after planting in a normal year without damaging sprouted (1-2") seedpieces.

2. Zone-subsoiling lowers bulk densities in the bed, and this effect persists until harvest. The reduced bulk density helps increase infiltration, and reduce runoff and erosion. The reduced bulk density also contributes to a slight early season warming of beds. Zone-subsoiled beds were generally more friable and easier to dig.

3. Zone-subsoiling produced a slight emergence advantage in several instances. This earlier emergence may contribute to the shift toward larger tubers seen in most studies.

4. In most studies yield and/or grade improved with zone-subsoiling. In no study was yield or grade significantly reduced by zone-subsoiling.

On the negative side:

1. Zone-subsoiling caused some bed cracking and piping in the furrow irrigated system. This was an inconvenience but was manageable and caused no yield or grade reduction.

2. Accelerated emergence could risk late frost damage in some areas.

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